



Challenges of Designing High Power Converter for Aerospace Applications

Kaz Furmanczyk
Principal Engineer
ELDEC Corporation

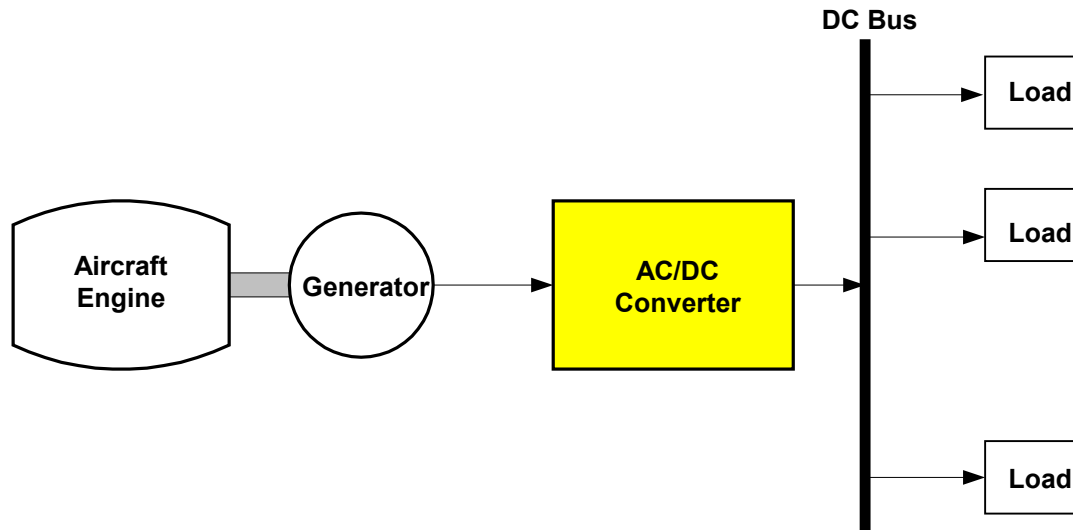
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- Subject Introduction
- Overview of Aircraft DC Power Generation
- AC/DC Converter Design Approaches on Airplane
- High Power Converter Design Challenges
- Implementing Modeling and Simulations for Design Optimization - Examples

- Move towards **More Electric Airplane** continues
- Future airplanes will require higher rating of power conversion equipment
- Higher power will force increase in DC voltage bus (to keep cable size/weight to a reasonable level)
- Higher power and higher DC voltage open **new challenges for power conversion equipment**

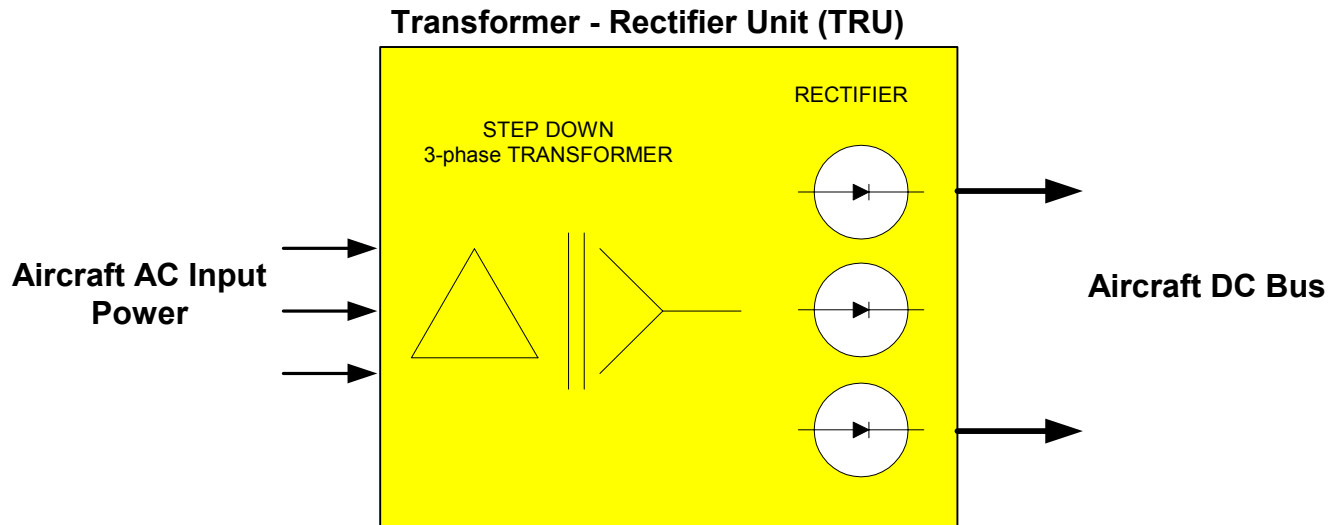
Simplified Aircraft Power System



DC Bus:

Currently: 28 Volts DC on commercial airplanes
28 or 270 Volts on military airplanes

AC to DC Power Conversion on an airplane is typically performed by Transformer Rectifier Unit (TRU)



- Simplicity
- High reliability
- Effective fault clearing capabilities
- Performance improvements, when used multi-phase rectification techniques
 - DC output ripple reduction

$$\text{Ripple } V [\%] = [1 - \cos(360/2m)] * 100$$

- Input current harmonics reduction

$$\text{Harm} = km \text{ +/- } 1$$

$$\text{Mag} = 1/(km \text{ +/- } 1)$$

m - number of rectification pulses

k - any positive integer

TRU Design Approaches Summary

Category	Output Voltage Ripple [%]	Input Current THD [%]	Applications
6-pulse	14	28-33	Limited to low power (< 500 VA); seldom used for aerospace applications due to high THD
12-pulse	3.4	9-14	Commonly used for aerospace applications. Topology acceptable by most current applications
18-pulse	1.52	6-9	Preferred for higher power applications and where power quality is important.
24-pulse	0.86	4-6	Used for special needs in aerospace applications, where power quality is critical.
30-pulse	0.55	1.5-2.5	Used for high power special needs applications. Meets Navy power quality specification requirements for current harmonic distortion (requirements for THD < 3%)

Challenges in AC/DC Converter Requirements

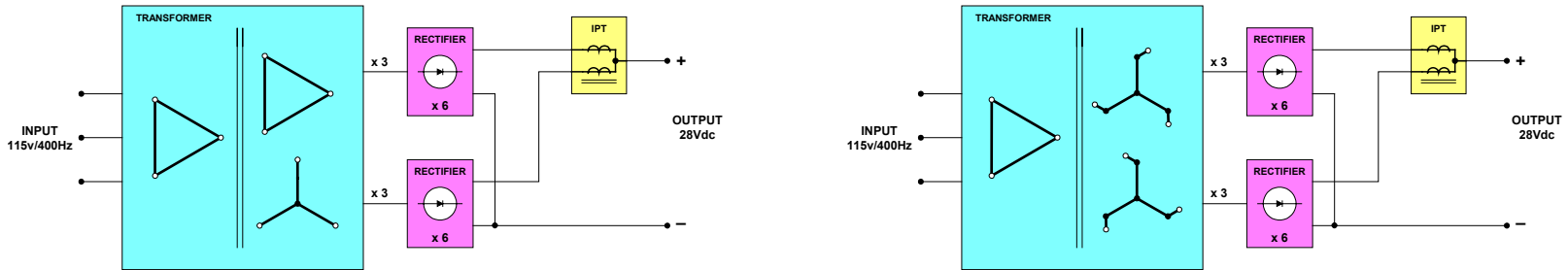
- Present Requirements (typical)
 - Input: 115V/400Hz
 - Output: 28Vdc; power up to 10 kW

- Expected Future Requirements
 - Input: 230V, variable frequency
 - Output: 270Vdc or higher; power 100 kW plus

- It is important to analyze design approaches to achieve:
 - Lowest possible weight
 - Highest conversion efficiency

- It become absolutely critical to model and analyze high power units

Challenges in Topology Selection - Example



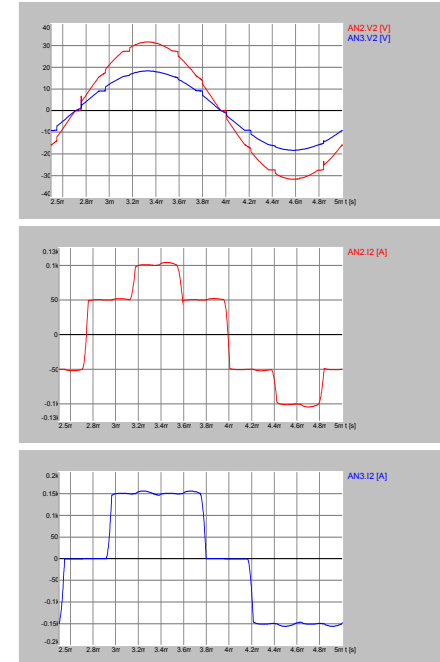
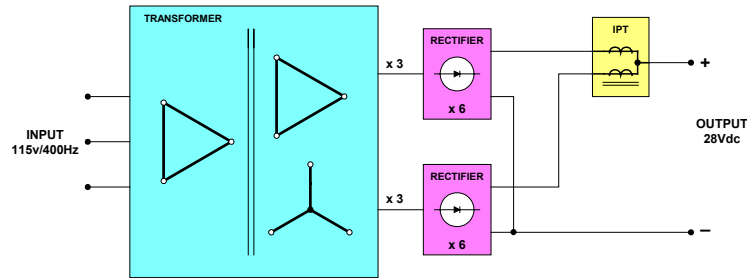
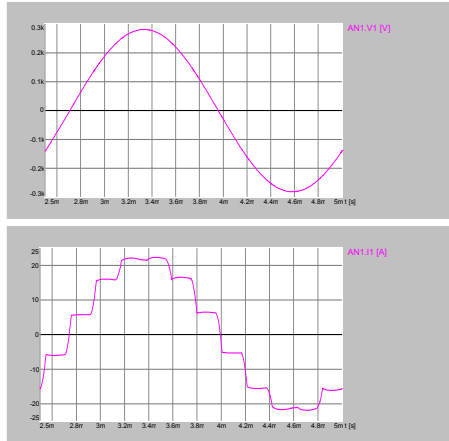
- Both topologies utilize 12-pulse conversion/rectification techniques
- Secondary voltages are shifted 30 deg. to obtain 6-phase transformer output voltage
- Input current waveforms and output voltage ripple are identical
- **Which approach is more suitable for aerospace applications ?**

- Define transformer Power Rating Factor (PRF):

$$PRF = [sum(V_{rms} * I_{rms})] / (V_{in} * I_{in} + V_{out} * I_{out})$$

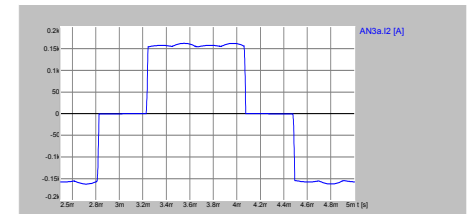
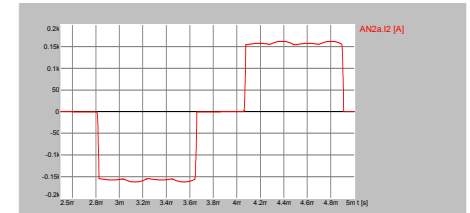
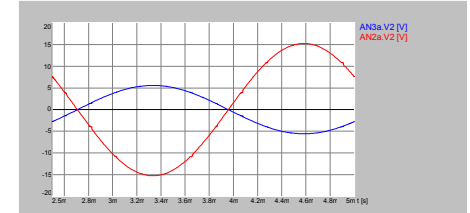
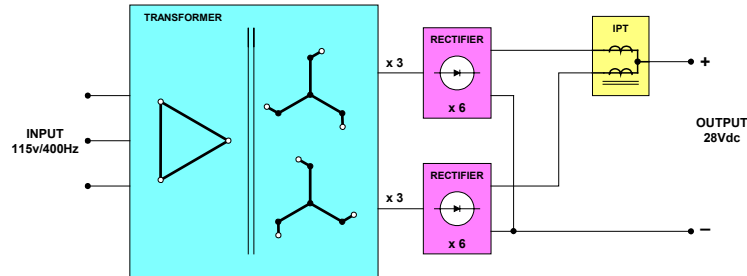
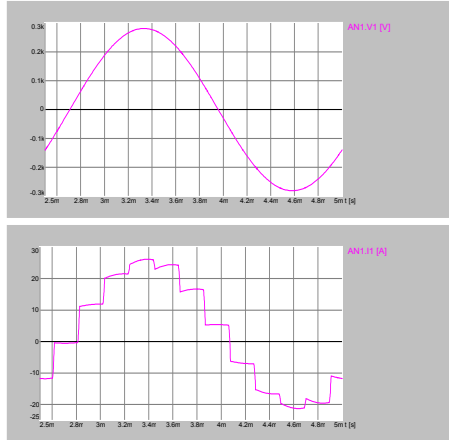
- PRF is directly proportional to the transformer weight and size
- For aerospace applications smaller transformer is desirable

Challenges in Topology Selection - Example cont.



12-pulse D-dy #1					
Branch Name	Voltage [Vrms]	Current [Arms]	Power [VA]	No. of legs	Total Power [VA]
Primary - D	199.1	16.2	3225.42	3	9676
Secondary - y	13.2	126.7	1672.44	3	5017
Secondary - d	22.8	72.3	1648.44	3	4945
Total TRU Processing Power [VA]				9	19639
Input Power	115	28.1	3231.5	3	9695
Output Power	28.5	309.7	8826.45	1	8826
Total TR Power [VA]					18521
Transformer Size Factor					1.06

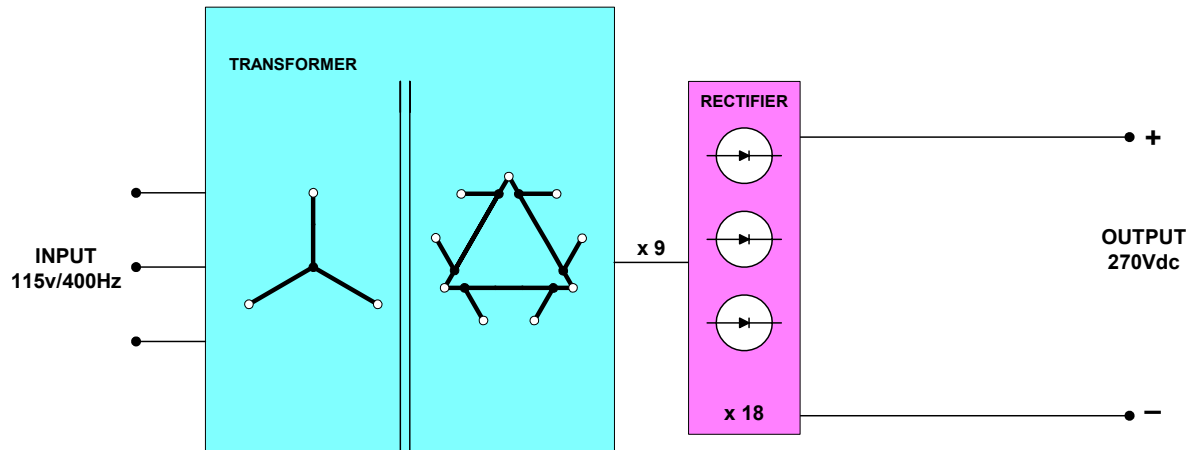
Challenges in Topology Selection - Example cont.



12-pulse D-2z #5					
Branch Name	Voltage [Vrms]	Current [Arms]	Power [VA]	No. of legs	Total Power [VA]
Primary - D	199.1	16.4	3265.24	3	9796
Secondary - y	10.8	128.4	1386.72	6	8320
Secondary - z	3.96	128.4	508.464	6	3051
Total TRU Processing Power [VA]				15	21167
Input Power	115	28.9	3323.5	3	9971
Output Power	28.4	311.3	8840.92	1	8841
Total TR Power [VA]					18811
Transformer Size Factor					1.13

Challenges in Topology Selection

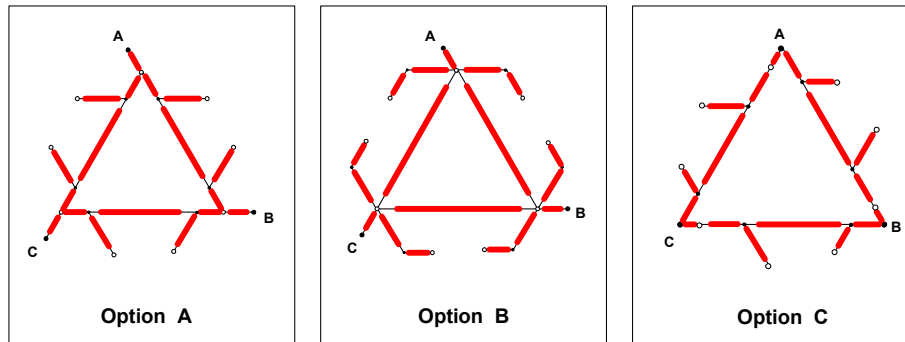
- High power converters create greater challenge



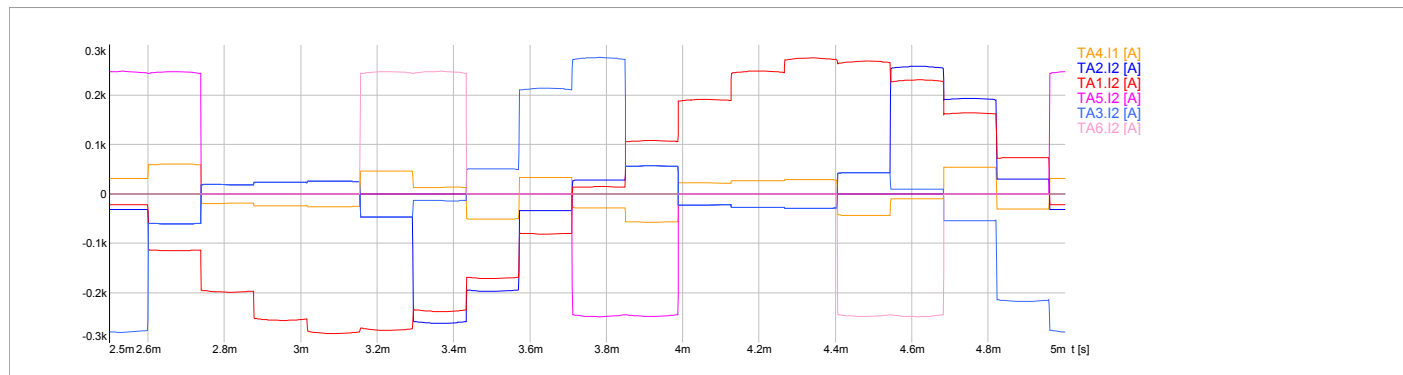
- For high output voltage transformer can be replaced with an autotransformer for further size reduction

Challenges in Topology Selection

- Some of available Autotransformer options, having identical performance:



- It is almost impossible to analyze topology without converter modeling and running simulations (current waveforms in transformer winding become very complex)

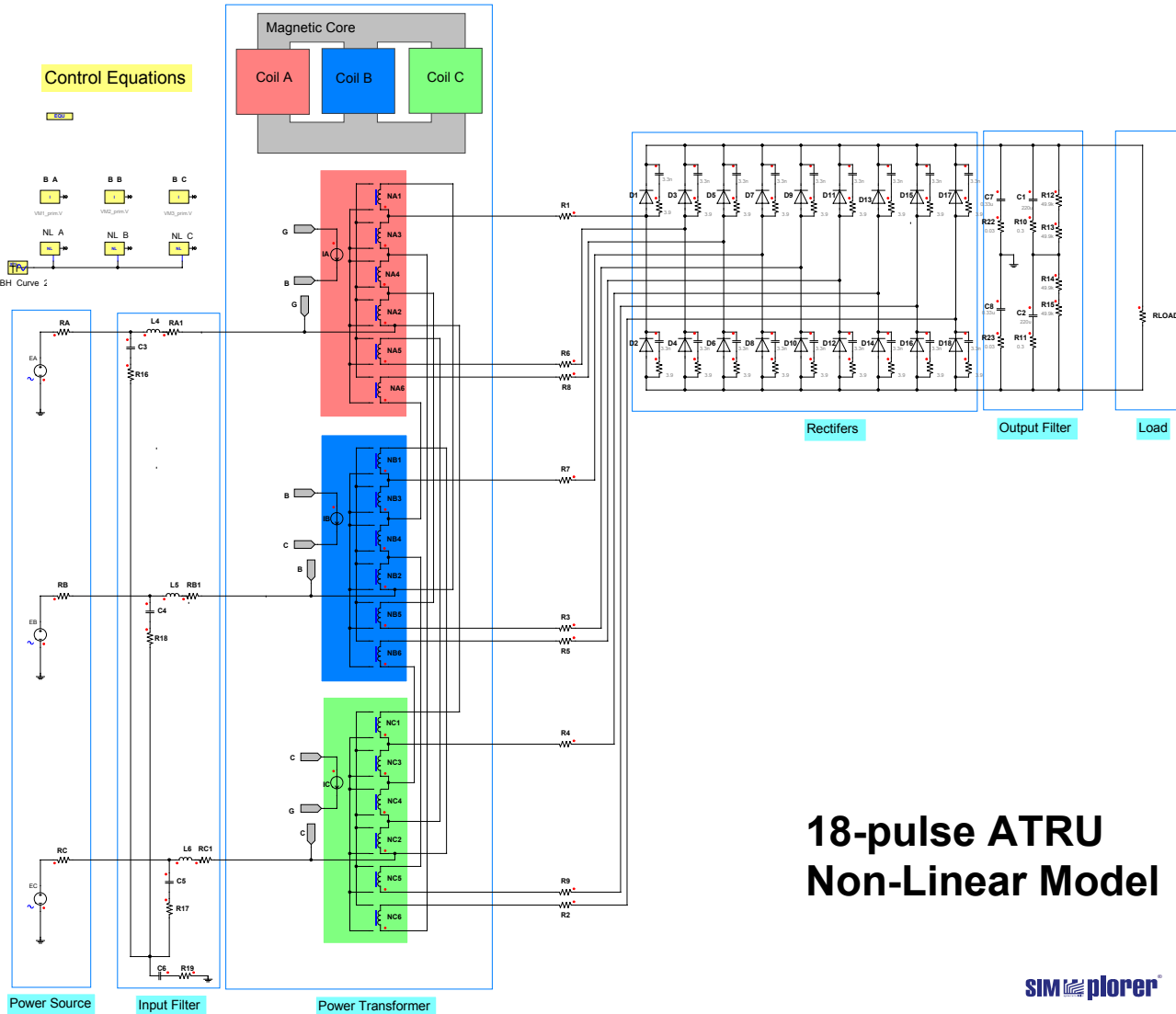
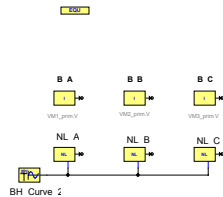


Simulation Model Example

Input Parameters

FREQ=400 **PHI0=0**
P_Load=135*1
 NA=11 8001-4.50e11.5
 NB=11 8001-4.50e11.5
 NC=11 8001-4.50e11.5
 ND=11 8001-4.50e11.5
 NE=11 8001-4.50e11.5
 LF=1000
 LFC=40.00001
 ATRU Schematic.ssh
 Simulation properties:
 Step width max
 Step width min
 Simulation end time

Control Equations



**18-pulse ATRU
Non-Linear Model**

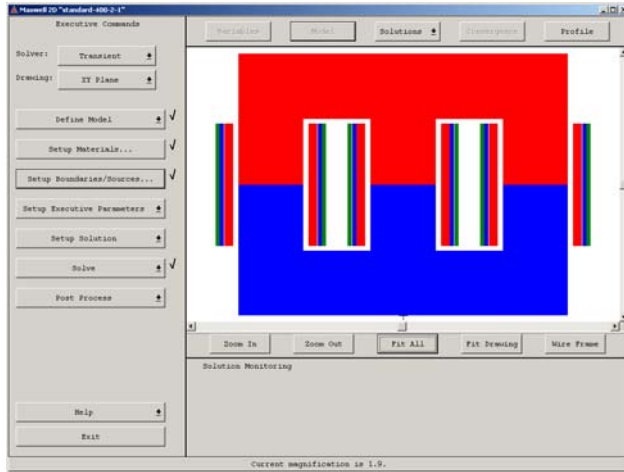
Transformer Construction Challenges

- Choosing winding material (copper, aluminum)
- Selecting conductor shape (round wire, square wire, foil)
- Defining and optimizing core geometry and aspect ratio

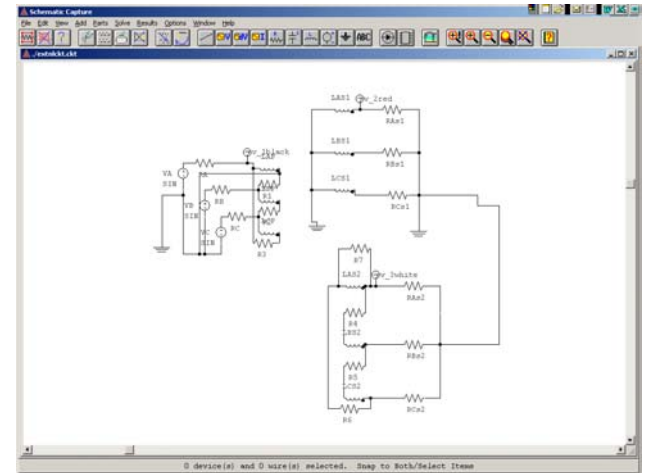
- It is not practical to build and test each considered option
- Design iterations and optimizations need to be performed on paper
- High power converters can be build only once

Transformer Construction Optimization

Define core geometry
and winding configuration



Convert geometry
and materials into
electrical parameters



Simulate
performance

Adjust and optimize

Core Losses
Winding Losses
Leakage Inductance
Regulation

- More Electric Airplane will require higher power conversion equipment rating
- Weight and power dissipation (efficiency) of power conversion equipment are critical factors influencing aircraft performance
- It is necessary to have set of design tools in place to be able to optimize high power converters design and meet new challenges of future aerospace needs
- It is not practical to optimize designs by “build and try” methods
- High power converters can be built only once

- ELDEC specialize in design and manufacturing of power conversion equipment for aerospace applications
- Standard available products:
 - TRUs: 115Vac/400Hz, 3-phase to 28Vdc - up to 300 Amps
 - Regulated TRUs: 115V/400Hz, 3-phase to 28Vdc - up to 400 Amps
 - ATRUs: 115V/variable frequency, 3-phase to 270Vdc - up to 90kW
 - 230V/3-phase/variable frequency to 540dc - up to 150kW
 - Aircraft Battery Chargers
 - Power Conversion Units
 - Information: ELDEC web side: www.eldec.com
- Technical Information: Kaz Furmanczyk, Principal Engineer
 - Tel. 425-743-8106
 - e-mail: Kaz.Furmanczyk@craneaerospace.com